Optimization of highly Negative Dispersion at L-band region in quadrupleclad profile

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Abstract:-*To optimize the high negative dispersion at L-band region for the quadruple clad profile with variation in core and cladding radius. The main feature of this work is to achieve the fiber in DWDM application as well as dispersion compensation, high effective area, low bending loss and low nonlinear refractive index, which used at various platy of communication. Due to this effective refractive index profile, the fiber dispersion has highly negative dispersion. In an optimization design case, the maximum negative dispersion is achieved by -886ps/km.nm at 1.6µm (L band) regime.This fiber has a high FOM (726 ps/nm dB) is achieved at L band region compare with triple clad profile.*

Keywords: DWDM(Dense Wavelength Division Multiplexing), high effective area, dispersion compensation, Triple Clad and Quadruple Clad profile.

1.Introduction

An optical waveguide is a structure that can guide a light beam from one place to another. The most extensively used optical waveguide is the step index optical fiber that consists of a cylindrical central dielectric core, clad by a dielectric material of a slightly lower refractive index. These fibers are referred to as step index fibers because of the steps discontinuity of the index profile at the core cladding interface. The main characteristics of fiber are Numerical aperture, attenuation, pulse dispersion, Loss mechanism, group delay, effective area, nonlinear refractive index.

The index profile decides the performance of a fiber and application of fiber in optical communication. Here designed index profile is quadruple clad profile which can be used for compensating the dispersion in negative regime. The WDM system has a number of user at a time with variation in frequency separation. Generally the fiber has pronounced with high dispersion and attenuation. They are several types of optical fiber where characterization of cable can be optimized in relevant to the desired application.

2.Design of quadruple clad profile

Light can be total internally reflected at the core and cladding interface, light launched at the input end may also be guided along cladding. To obtain higher compensability of dispersion compensation with a least macro bending loss at an optimum bending radius at L-band of optical communication. This profile has depressed cladding with pure silica and Fluorine-doped silica material used for core and cladding regions, respectively.Total diameter taken by 125µm then maximum refractive index is 1.480 and lowest refractive index is 1.464. The fiber design softwareOptifiberv.2.0has been used.

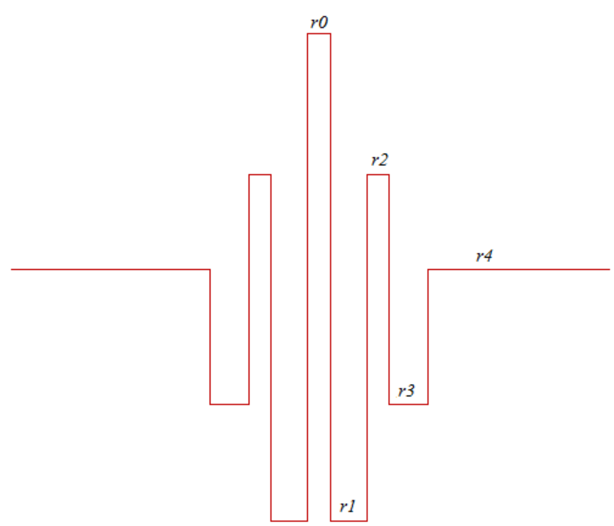

Figure 1: Refractive index profile

From the refractive index profile can be designed as separating clad region from the core by adding further region. The region can be differentiated by varying the refractive index values and radius of the core and clad respectively.Since the design module can be described as Refractive index of the core (n(r0))=1.480, |r0|≤2.8µm

Refractive index of the cladding (n(r1))=1.4641, |r1|≤8.6µm
Refractive index of the cladding (n(r2))=1.4754, |r2|≤5.2µm
Refractive index of the cladding (n(r3))=1.4679, |r3|≤9µm
Refractive index of the cladding (n(r4))=1.4723, |r4|≤99.8µm,
Where r0,r1,r3,r4,r5 represents the width of the region.

3. Characteristics of quadruple clad profile

Using OPTIFIBER simulation software, we have obtained below depicted characteristics of our optimized DCF at L band region.

A. Dispersion

Dispersion represents one of the most important characteristics of an optical fiber that determines the information- carrying capacity of a fiber optic communication system. In telecommunication the term of dispersion is used to describe the processes which cause that the signal carried by the electromagnetic wave and propagating in an optical fiber is degraded as a result of the dispersion phenomena.

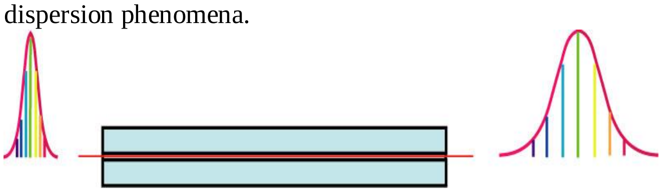

Figure 2: Basics of dispersion

This degradation occurs because the different components of radiation having different frequencies propagate with different velocities.
We distinguish various kinds of dispersion,
1. Chromatic dispersion
  - Waveguide dispersion (optical)
  - Material dispersion
  - Polarization mode dispersion
2. Mode dispersion

The different group velocities of the frequency components of a pulse cause it to broaden as it travels along a fiber. This spreading of the group velocities is knows as chromatic dispersion or group velocity dispersion (GVD). Expanding β to third order in a Taylor series yields

$$\beta(\alpha)=\beta_0(\alpha_0)+\beta_1(\alpha_0)(\alpha-\alpha_0)+\frac{1}{2}\beta_2(\alpha_0)(\alpha-\alpha_0)^2+\frac{1}{6}\beta_3(\alpha_0)(\alpha-\alpha_0)^3 \quad \text{-------------} \ (1)$$

the first term describes a phase shift of the propagating optical wave. The second term produces a group delay

$$\tau_g=\frac{z}{v_g}=-\frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda} \text{-------} \ (2)$$

Where z is the distance traveled by the pulse and $v_g=\frac{1}{\beta_1}$ is the group velocity. The third term describes the group velocity of a monochromatic wave depends on the wave frequency. The factor β_2 is called the GVD parameter, and the dispersion D is related to β_2 through the expression

$$D=-\frac{2\pi c}{\lambda^2}\beta_2 \quad \text{--------} \ (3)$$

In the fourth term known as the third order dispersion. This term is important around the wavelength at which $\beta_2$equals zero. The third order dispersion can be related to the dispersion D and the dispersion slope

$$S_0=\frac{\partial D}{\partial\lambda}\text{.----------} \ (4)$$

$$\beta_3=\frac{\lambda^2}{(2\pi c)^2}(\lambda^2 S_0+2\lambda D)\text{-----------} \ (5)$$

The determination of dispersion and dispersion slop of quadrupleclad profile of DCF is based on equation 3 and 4.

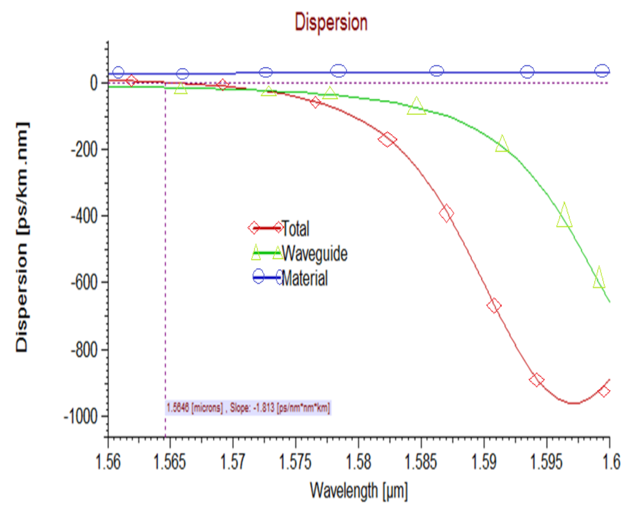

Figure3: dispersion of the DCF

From the figure 3 the optimization of dispersion is achieved by quadruple clad profile as 886ps/km.nm at 1.6µm(L band) regime. Here, optimization can be done by varying width of core and cladding regime, by further variation in core and cladding radius although the negative dispersion is achieved but confinement loss will also be high. In order to consider confinement loss too we need to take care of design and dispersion slope can also be calculated as -1.312ps/nm*nm*km at 1.563µm. the negative dispersion achievement for this specific profile is calculated for the fundamental modes LP_{01}, for higher order modes the dispersion plot and confinement factor may be changed due to variation in intensity profile and velocity.

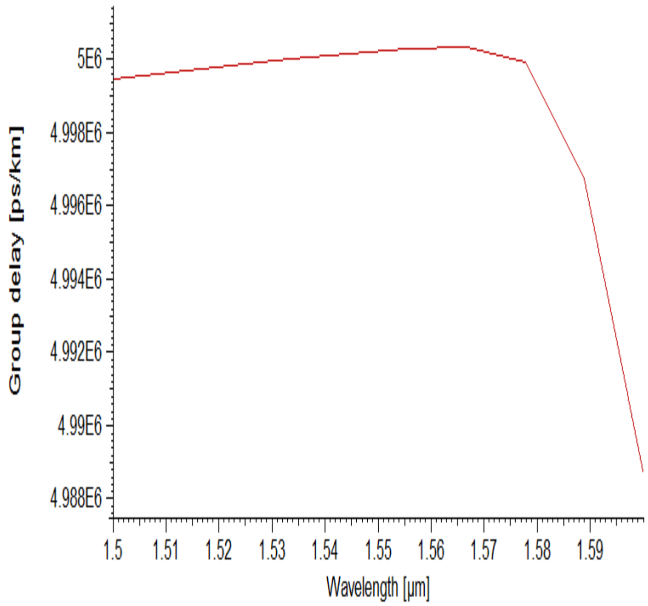

Figure 4: Group delay

The calculation of group delay or time delay of DCF based on equ.2 based on the obtained result, as shown in the fig. 4, we note the group delay from 1.5µm to 1.6µm.

B. Analysis of Macro bending loss

Macro bending and micro banding losses are very important in the design of fibers. The bending losses are primarily a function of the mode field diameter. Generally, the smaller the mode field diameter(i.e., the tighter the confinement of the mode to the core), the smaller the bending loss. The macro bending loss in terms of attenuation coefficient γ is defined in dB/km as:

$$\boldsymbol{\alpha_{macro}} = \frac{\mathbf{10}}{\boldsymbol{L}}\mathbf{log[exp(\gamma L)]} \quad \text{-------- (6)}$$

The attenuation coefficient given by,

$$\boldsymbol{\gamma} = \frac{\mathbf{1}}{\boldsymbol{L}}\boldsymbol{In}\left[\frac{\boldsymbol{P_{in}}}{\boldsymbol{P_{out}}}\right] \quad \text{------- (7)}$$

Where L for length of transmission line in km.

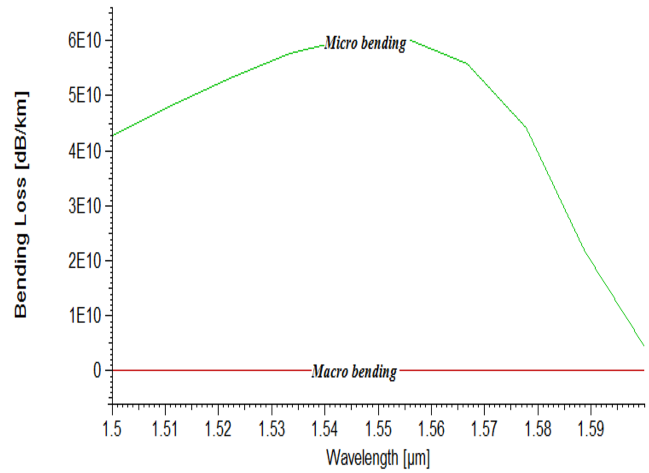

Figure 6: Bending losses with bending radius of 5mm

The above figure to obtained maximum negative dispersion with minimum macrobending loss by using bending radius of 5mm in quadruple clad profile of DCF .

C. Splice and Material loss

The particular technique selected for joining the fibers depends on whether a permanent bond and easily demountable bond connection is desired. A permanent bond is generally referred to as a splice, whereas a demountable joint is known as a connector. The optical power that can be coupled from one fiber to another is limited by the number of modes that can propagate in each fiber. The total no of modes can be found from above expression.

$$\boldsymbol{M} = \boldsymbol{k^2}\int_{\mathbf{0}}^{\boldsymbol{a}}[\boldsymbol{n^2(r)} - \boldsymbol{n_2^2}]\boldsymbol{rdr} \quad \text{---------- (8)}$$

Where n(r) defines the variation in the refractive index profile of the core, for a step index fiber with a core radius a and a cladding index n_2, and with k=2π/$\boldsymbol{\lambda}$. The material loss is a combination of OH,IR and UV absorptions with Rayleigh scattering. In fig.7.thesplice loss is gradually decreased in the L band region and in fig.8. Obtained material loss is 0.2dB/km at 1.5 to 1.6µm

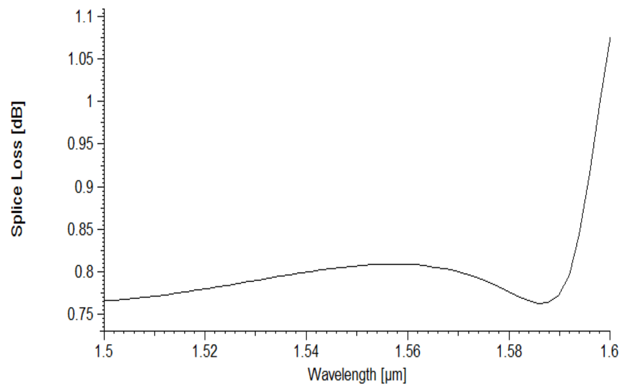

Figure 7: Splice loss for DCF

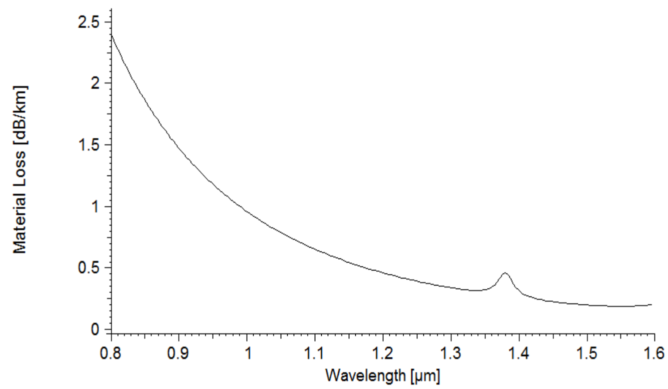

Figure 8: Material loss for DCF

D.Effective Nonlinear Refractive Index

Usually one of the design goals when constructing a fiber is to minimize its nonlinearities. The effective nonlinear coefficients of optical fibers depend on the nonlinear indices of the bulk materials building the fiber and on its wave guiding properties: shape of modes, degree of confinement, etc. As a result it can vary within broad limits. The calculates the eff. nonlinear coefficient as

$$\boldsymbol{n_2^{eff}} = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \boldsymbol{n_2(x,y)|F(x,y)|^4 dxdy}}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \boldsymbol{|F(x,y)|^2 dxdy}} \text{ ---- (9)}$$

Where$n_2(x,y)$ is the user-defined spatially dependent nonlinear refractive index ofthe various fiber layers and F(x, y) is the normalized mode field pattern.

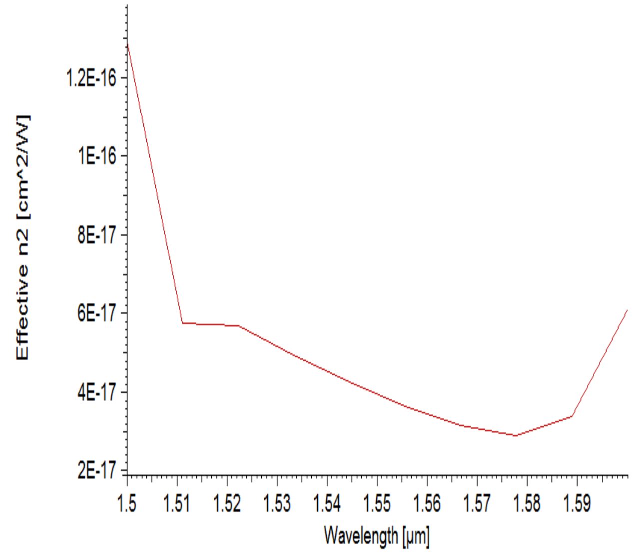

Figure 9: Effective Nonlinear Refractive Index

Figure 9.Depicts the Effective Nonlinear Refractive Index (n_2) characteristics versus wavelength of our optimized fiber.

D. Figure Of Merit

A high Figure of Merit signifies that the dispersion compensating fiber module adds less loss to the system. FOM for dispersion compensating fibers defined as

$$\boldsymbol{FOM = -\frac{D_{DCF}}{\alpha_{DCF}}} \dots\dots\dots \mathbf{(10)}$$

From the equation D_{DCF} for dispersion coefficient for DCF and α_{DCF} for attenuation for DCF.The attenuation of DCF is typically in the range 0.4–0.7 dB/km depending on the fiber design.so total attenuation occurred by following equations

$$\boldsymbol{\alpha_{tot} = \alpha_{splice} + \alpha_{scattering} + \alpha_{waveguide}} \dots \mathbf{(11)}$$

$$\boldsymbol{\alpha_{splice} = \alpha_{UV} + \alpha_{IR} + \alpha_{abs}} \dots\dots \mathbf{(12)}$$

with α_{UV} being the attenuation due to absorption on electronics transitions, α_{IR} the attenuation due to multi phonon absorptions, α_{abs} the attenuation due to absorption on impurities or defects, $\alpha_{scattering}$ the attenuation due to scattering and$\alpha_{waveguide}$the waveguide dependent attenuation. In figure 10 represents the Figure of Merit of QC(Quadruple Clad) compare with TC(Triple Clad) with various wavelengths.

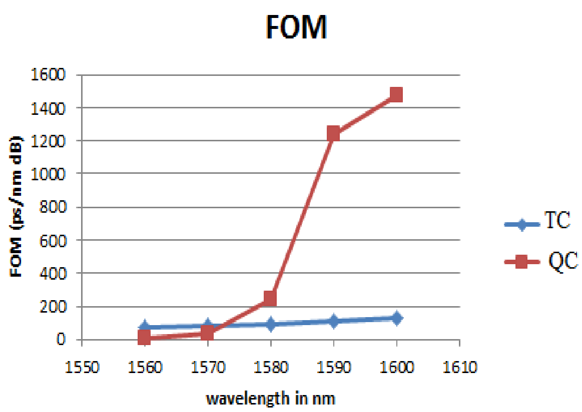

Figure 10: FOM for QC and TC

4.Conclusions

In this paper, an optimized high negative dispersion at L-band regime for the quadruple clad profile with variation in core and cladding radius (-886ps/km.nm at 1.6µm). The calculated results show that the fiber has low dispersion slope (-1.312ps/nm*nm*km at 1.563µm) while maintain minimum bending, splice and material losses and also reduced Effective Nonlinear Refractive Index n_2 (2.88×10^{-17}cm^2/w at 1.577µm) is achieved.Then achieved high Figure of Merit(726 ps/nm dB) compare with triple clad profile. Thus, the optimized quadruple clad profile of DCF will be very useful for long haul transmission.

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